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Abundance of and threats to the snow leopard in various regions of its occurrence

Početnost a příčiny ohrožení sněžného leoparda v různých oblastech jeho výskytu

Bachelor thesis

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***Prohlášení:***

Prohlašuji, že jsem závěrečnou práci zpracovala samostatně a že jsem uvedla všechny použité informační zdroje a literaturu. Tato práce ani její podstatná část nebyla předložena k získání jiného nebo stejného akademického titulu.

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**Abstract:**

Snow leopard (*Panthera uncia*) is an endangered species and its population size is steadily declining. This thesis attempts to introduce and analyse the main factors threatening its survival with reference to each country of its occurrence: China, Bhutan, Nepal, Pakistan, Afghanistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, Russia and Mongolia. To conserve the remaining snow leopard populations, it is necessary to detect its distribution in various areas. Here, recent data about its worldwide distribution are presented. Snow leopard has a very secretive lifestyle, which makes estimation of its abundance quite difficult. Therefore, I also present here an overview of methods, such as sign survey, capture-recapture, predator:prey biomass ratios, photo-capture rate and genetic analyses, used for estimation of abundance of snow leopard with reference to conducted studies. I discuss their advantages and disadvantages under different conditions.

**Key words:** snow leopard, abundance, threats, worldwide distribution, conservation

**Abstrakt:**

Sněžný leopard (*Panthera uncia*) patří mezi ohrožené druhy se stále klesajícími počty přežívajících jedinců. Tato práce se snaží poukázat na hlavní faktory ohrožující jeho přežití s ohledem na jednotlivé země jeho výskytu: Čínu, Bhútán, Nepál, Indie, Pákistán, Afghánistán, Tádžikistán, Uzbekistán, Kyrgyzstán, Kazachstán, Rusko a Mongolsko. Pro zachování dosud žijící populace sněžného leoparda je nezbytné znát jeho rozšíření na jednotlivých lokalitách. V této práci jsou uvedeny dosavadní dostupné údaje o jeho celosvětovém rozšíření. Tajnůstkářský způsob života sněžného leoparda velmi ztěžuje způsoby měření jeho abundance. Dalším cílem této práce je snaha shrnout dosavadní metody (průzkum za pomoci znaků, metoda zpětného zachytu, poměr biomasy predátor-kořist či genetické analýzy) používané pro odhady jeho početnosti, pokusím se mezi sebou jednotlivé metody srovnat s poukázáním na některé provedené studie. Práce se také zaměřuje na jejich výhody a nevýhody a za jakých podmínek je vhodné je použít.

**Klíčová slova:** leopard sněžný, abundance, ohrožení, celosvětové rozšíření, zachování

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## 1. Introduction

Snow leopard, *Panthera uncia* (Schreber 1775), *syn. Uncia uncia* is a member of the genus *Panthera* in the family *Felidae*. It is most closely related to the tiger, *Panthera tigris* (Jackson et al. 2008). The snow leopard is whitish-grey (tinged with yellow) in colour, and patterned with dark grey rosettes and spots (McCarthy & Chapron 2003). In contrast with other big cats, it has under-developed fibro-elastic tissue in vocal apparatus (Rajput 2009), so it is not able to make full deep roar. In general, snow leopard lives solitarily, though group of up to six snow leopards have been reported (McCarthy & Chapron 2003). In the 1972 IUCN's Red List of Threatened Animals it is listed as "endangered" species (EN) due to its small population worldwide.

Its main habitat consists of alpine and sub-alpine regions with rugged and steep terrain separated by ridges, cliffs, rocky outcrops and gullies (Ale et al. 2014, Schaller 1977, Jackson & Ahlborn 1989). Nevertheless, its occurrence was proved even in flat and rolling terrain in Tibet and Mongolia, wherever there is ample of hiding cover (Jackson et al. 2008). Usually it inhabits areas of 3,000-4,500 m altitude. However, at its northern range limit it occurs at much lower elevations: 900-2,500 m (McCarthy et al. 2003). Its home range fluctuates between 10 to 40 km<sup>2</sup>, for instance in Nepal (Jackson & Ahlborn 1989). However, it may reach up to 140 km<sup>2</sup>, like in Mongolia, due to lower prey densities and open terrain there (McCarthy et al. 2005). Snow leopard density ranges from 0.1 to 10 or even more individuals per 100 km<sup>2</sup> (Jackson et al. 2008).

Snow leopard main natural prey includes ibex (*Capra ibex*), argali (*Ovis ammon*), bharal or blue sheep (*Pseudois nayaur*) (Jackson et al. 2008, McCarthy et al. 2008). The natural distribution of these species correlates with snow leopard occurrence. One snow leopard needs about 20 to 30 adult blue sheep annually (Jackson et al. 2008). For instance, the habitat of blue sheep is spaced out in mountainous terrain from the Qilian Mountains in the north to the Himalayas in the south (Aryal et al. 2014), which includes Nepal, India, China, Pakistan and Mongolia. Unfortunately, thorough population estimates are deficient (Schaller 1977; Oli et al. 1993). Its other prey species include pika (*Ochotona spp.*), hares (*Lepus spp.*), marmot (*Marmota spp.*), game birds, and small rodents (Jackson et al. 2008). Domestic

livestock is a potential prey of snow leopard. E.g., in many cases snow leopard opportunistically kills domestic livestock in larger proportion than wild prey. Our knowledge of its diet range and especially of the relative importance of individual species in the diet is still anecdotal and therefore, it would be appropriate to conduct additional surveys to better understand these trophic interactions in the leopard-prey system (Aryal et al. 2014).

## **2. *Threats to the snow leopard***

The main threats to the snow leopard encompass illegal trade, conflict with locals (human-snow leopard conflict), lack of conservation capacity, awareness and policy, and climate change (Jackson et al. 2008).

### **2.1. *Human-snow leopard conflict***

Conflict with local people is the most significant threat to snow leopard. This conflict is caused by livestock depredation which leads to retaliatory killing (Jackson et al. 2008). Snow leopard home range overlaps with extensive agro-pastoral land, which is located inside and outside of protected areas. The rapid increase of livestock depredation is caused by decline in abundance of wild prey due to low primary productivity, competition for forage with livestock, and hunting of ungulates for meat (Jackson et al. 2008, Bagchi and Mishra 2006). Snow leopard's population density positively correlates with the density of its prey (McCarthy et al. 2003). Livestock is an important food source for snow leopards, in some areas it makes 58% of their food diet (Jackson et al. 2008).

Even though killing of snow leopard is prohibited, there have still been reported cases of retaliatory killings of snow leopard by the herders in the past, for instance in Nepal in the Kanchenjunga Conservation Area (KCA) (Ikeda 2014). Most herders have a negative attitude to the snow leopard conservation programmes because of an insufficient compensation for livestock damage and due to non-realistic procedure of verifying livestock depredation by snow leopard (Ikeda 2004). The economic damage is much higher than the possible compensation which the herders would get from the government. There are few methods of estimating the monetary value of livestock damage which were used in prior studies such as half of the per capita average income in Himachal Pradesh, India (Mishra 1997) or quarter of the per capita average annual income in Nepal (Oli et al. 1994). Ikeda in the KCA estimated the monetary value of livestock damage in the context of local herder's economy in the Ghunsa Valley, Nepal (Ikeda 2014). The economic impact of loss of herder's livestock differs



between areas. For example, in western Nepal, herders possess sheep and goats the same as yaks and yak hybrids, while in eastern Nepal, yak and yak hybrid pastoralism is more important, so in general they possess few animals in contrast with hundreds of goats and large sheep herds in western Nepal. Therefore, the impact of losing one of their livestock is larger in eastern than in western Nepal (Ikeda 2004). However, occasionally more than 100 sheep or goats have been killed by snow leopard (so-called surplus or mass killing), which may cause a huge economic loss to local herders (Shrestha, pers. comm.) For households with an average herd size (36.6 head in KCA) common annual damage by snow leopards does not have such a big impact to fundamental livelihood. However, in the worst scenario of livestock depredation, households with medium or small-sized herds (<40 heads) might risk their living conditions becoming unsustainable or having to withdraw from yak pastoralism (Ikeda 2004).

Killing of snow leopard in indemnification for livestock depredation and reduction of natural prey is inherently challenging in the Himalayan region (India, Nepal, Bhutan, Tibetan Plateau and other southern China), Karakorum and Hindu Kush (southwest China, Pakistan and Afghanistan). Mere reduction of natural prey due to illegal hunting occurs in Commonwealth of Independent States and western China (Kyrgyzstan, Kazakhstan, Xinjiang province of China, Uzbekistan and Tajikistan) (Jackson et al. 2008).

## **2.2. *Illegal trade***

Illegal trade is likewise a relevant threat to the snow leopard. Snow leopards are being killed not just in revenge but also for commercial purposes. The major product of snow leopards in demand is pelt, followed by claws, meat, male organs, and bones used in Chinese medicine to substitute tiger bones (Theile 2003). Due to the growing Chinese economic also the illegal trade increases, for instance, in adjoining Mongolia (Wingard and Zahler 2006) or in Afghanistan, where it is challenging to avoid it because of the current military conflict (Habibi 2004). With the fall of the Soviet Union in the 1990s, in Kyrgyzstan and other recently independent states, increased unemployment and corruption in the mountainous regions led to growth of black market trade with wildlife products (McCarthy et al. 2010). For instance, in Kyrgyzstan the people originating from villages close to protected areas are

miserably paid and in some cases have to resort to poaching of wildlife within the park boundaries (McCarthy et al. 2010). Nowadays some of the quondam socialist republics continue to contend with the promotion of a sustainable development agenda (McCarthy et al. 2010). Today, the level of poaching is lower, but in many of the former Soviet republics it continues.

### **2.3. *Lack of awareness and policy***

The general lack of awareness at both local and national levels for the need to conserve wildlife and especially predators further hinders conservation efforts (Jackson et al. 2008).

To estimate abundance of snow leopard in some cases, e.g. when genetic analyses are used, it is needed to transport the samples across the countries. Impossibility of trans-boundary sample transport complicates the surveys conducted especially in areas adjacent with politically sensitive international borders. In the IUCN's research, lack of trans-boundary cooperation is challenging in almost every location of snow leopard range such as Himalayan region and Commonwealth of Independent States and western China (Jackson et al. 2008). For instance, in Nepal, there is just one laboratory in Kathmandu specializing in wildlife, which is insufficient (Bikram Shrestha, pers. comm.). Majority of herders in Nepal complain about insufficient project management in terms of reliability and transparency (Ikeda 2004).

In some areas, e.g., in Kyrgyzstan, there is an insufficient legislative system in reserves. McCarthy et al. (2010) compared the composition of species between an unprotected area which is used as a hunting preserve by foreign companies and strictly protected national park (Sary Chat) in the Tien Shan Mountains of eastern Kyrgyzstan. Even though hunting is not permitted in Sary Chat, cases of poaching by rangers and local villagers were there reported in the past (Koshkarev and Vyrypaev 2000). On the other hand, after the breakup of the Soviet Union, Jangart was established as a foreign currency hunting reserve hosting non-nationals who come to Kyrgyzstan to hunt ungulate species (McCarthy et al. 2010). Unexpectedly, photo rates in camera traps in the unprotected area (Jangart) were higher than in the protected ones for most species (McCarthy et al. 2010). A possible explanation is

that Jangart is more isolated from local villages than Sary Chat, where rangers and their families have settled along the edges of the park (McCarthy et al. 2010).

This can reflect the fundamental problem in the reserve system in Kyrgyzstan – deficiency of auxiliary enterprises for local people. The government replaced park staff, some nongovernmental organization (CBF = Community Business Forum) and the International Snow Leopard Trust were involved but nonetheless there is still evidence of continuing poaching of some carnivores in and around the reserve (McCarthy et al. 2010).

Effective law enforcement and institutional capacity are problematic mainly along the northern range of snow leopard distribution (Russia, Mongolia, Tien Shan ranges and Altai in China), Karakorum and Hindu Kush (Afghanistan, southwest China and Pakistan) (Jackson et al. 2008).

Military conflict also has affected snow leopards, primarily by destruction of their habitats (landmines), secondary by encouragement of trade in wildlife (Jackson et al. 2008). This issue is problematic in the Himalayan region and Commonwealth of Independent States and western China.

#### **2.4. *Climate change***

Climate change is considered as a strong threat to biodiversity (Beaumont et al. 2011, McCarty et al. 2001, Thomas et al. 2004). In general, climate change destabilizes systems and their management such as balance between resource use by locals and wildlife biodiversity (Namgail et al. 2007, Sharma and Tsering 2009, Mishra et al. 2004, Comiso 2003). The United Nations Intergovernmental Panel on Climate Change forecasts that the global temperatures will increase by something between 1.4 and 5.8 °C by 2100 (IPCC 2001, Locky & Mackey 2009). Most areas of snow leopard home range, such as high altitudes and cold deserts in the Trans-Himalayan region, are considered as being among the most vulnerable ecosystems with respect to climatic changes (Christensen and Heilmann-Clausen 2009; Xu et al. 2009; Dong et al. 2009; Sharma and Tsering 2009; Aryal et al. 2012a, b).

The tendency of snow leopards to move to lower elevations will increase due to the movement of their prey, such as blue sheep in the Trans-Himalaya due to substantial changes in vegetation communities – grasses and many shrub species are no longer found in sufficient abundance at higher elevations and consequently blue sheep move to forage at

lower elevations where they encounter and raid human crops (Table 1, Aryal et al. 2013). Table 1 shows the predicted impact of climate change on livelihood, blue sheep and snow leopard which are interrelated. According to predictions based on bioclimatic models, about 30% of snow leopard habitat may be lost in the Himalayas due to shifting treeline and consequent shrinking of the alpine zone, mostly along the southern edge of the range and in river valleys (Forrest et al. 2012). In the majority of snow leopard range, people practice rotational grazing in which corrals are located in different elevations. Therefore livestock killing is correlated with herding practices (Shrestha pers. comm.). Increased crop raiding by blue sheep and depredations of livestock by snow leopard have adversely affected the livelihood of local people (Aryal et al. 2013).

Rangelands (%)	Livelihood (%)	Blue sheep (%)	Snow leopard (%)
Reduction in water sources (18)	Reduction in food and drier farmland (9)	Reduction in numbers (38)	Reduction in numbers and low sighting (41)
Reduction in grasses (33)	Reduction in livestock (4)	Crop raiding (16)	Increase in livestock depredations due to decrease in natural prey (24)
Drier (12)	Health problems with new diseases (3)	Movement downwards towards farmlands (14)	Approaching the villages (13)
Reduction in snowfall (27)	Reduction in drinking water and fewer irrigation channels (36)	Sightings near villages (4)	Change in use of habitat and change in predation behaviors to kill domestic livestock then natural prey (22)
Move towards desertification (10)	Changes in agricultural crop cultivation time (27)	Reduction in grazing land (20)	
	Increase in wind speed	Change in habitats use (8)	
	Economic crisis (7)		
	Water seepage and damage to traditional houses (14)		

**Table 1.** Overall impact of climate change based on four parameters. Source : Interview with local people (n=221). Data are the percentages of the 221 respondents that agreed with the statement (Source: Aryal et al. 2013)

### **3. *Methods of estimating snow leopard abundance***

To optimize the management of snow leopard, it is necessary to know its distribution within the area and relative abundance in different habitat types (Sheng et al. 2010). Its secretive lifestyle makes estimation of its abundance quite difficult. Methods used for estimation of snow leopard abundance include sign survey, capture-recapture, predator:prey biomass ratios, photo-capture rate and genetic analyses (McCarthy et. al. 2008). No photo of a wild snow leopard existed until 1980 (Schaller 1980). Now camera traps are available. They indicate that the method of live-capture (direct capture of an animal) is almost impossible to use because of very low rate of encounters: about 3/1,000 trap-nights (McCarthy et al. 2008).

#### **3.1. *Sign surveys (SLIMS)***

Snow Leopard Information Management System (SLIMS) was developed recently to monitor the abundance of snow leopards and their prey (Jackson & Hunter 1996). The system is based on standardized sign surveys which are used regularly. Sign survey is considered as an index of relative abundance of snow leopard relevant for comparison of areas with comparable topographies (Ale et al. 2014). This method can be helpful to monitor abundance trends of the same area on a long time scale, so long as it is complemented by additional methods such as genetic analyses (e.g., Janecka et al. 2008) or remote cameras (e.g., McCarthy et al. 2008). SLIMS is cheap, has a minimal impact on the studied species, and therefore it is most commonly applied for monitoring snow leopards (Schaller 1977, Schaller 1998, Wilson & Delahay 2001, Wolf & Ale 2009). As the majority of ecological problems can be tackled using only indices of density, absolute estimates of density unnecessary luxuries (Caughley 1977), SLIMS may be sufficient in most cases.

The guesstimate of Snow Leopard numbers based on sign abundance follows Jackson & Hunter (1996): 20 signs per kilometre could indicate 10 individuals per 100km<sup>2</sup> - a crude, quick and easy-to-use method, which has been useful in conservation planning in countries

where resources are scarce (Ale et al. 2014). It is appropriate to space out the cameras: install at least one camera per approximately 25 km<sup>2</sup>, as this is assessed to be the minimum home range of a female adult snow leopard (Jackson & Hunter 1996, Ale et al. 2014).

To determine transects for sign survey, it is necessary to hike through the region to detect all sites where suitable habitat and terrain exist for snow leopard and where its prey can occur. As Ale et al. (2014) did in Nepal, it is important to localise sites which are often used by snow leopard to move around in its home range such as narrow valleys, trails, ridgelines, and cliff-edges (Jackson & Hunter 1996). To locate these sites it is helpful to use 1:50,000 topographic maps as in Ale et al. (2014) or 1:100,000 topographic maps used by McCarthy et al. (2008) in Kyrgyzstan and China.

After locating the transects (sites with high probability of snow leopard occurrence) the snow leopard signs are being searched along these. In addition, to provide a useful comparison to information gathered along sign transects, it is possible to collect signs between the transect lines (McCarthy et al. 2008) in Nepal. Signs demonstrating snow leopard presence include scent (or spray) marks, scrapes, faeces, pugmarks (footprints), and rocks or boulders which snow leopards use to deposit their scent or to cheek-rub (Ale et al. 2014). Scrapes and scent marks are more expensive to detect than the faeces and pugmarks. However, they may give us more biological and ecological information (Schaller 1977, 1998).

	Transect	Length (km)	Feces	Pugmark	Scrape	Spray	Hair	Total	Total sign/km	Sign sites	Sign sites/km	Scrape/km
Season												
Autumn	9	7.2	19	10	33	4		66	9.2	46	6.4	4.6
Spring	15	11	15	6	90		1	112	10.2	38	3.5	8.2
Summer	27	19.4	22	3	16			41	2.1	23	1.2	0.8
Total		37.6	56	19	139	4	1	219	5.8	107	2.8	3.7
Study area												
Lower Mustang	3	24.4	45	15	56	4	1	121	5.0	77	3.2	2.3
Upper Mustang	18	13.2	11	4	83			98	7.4	30	2.3	6.3
Total		37.6	56	19	139	4	1	219	5.8	107	2.8	3.7

Table 2. Snow Leopard sign abundance in Mustang, Annapurna (Source: Ale et al. 2014)

According to surveys conducted in the Mustang District of Nepal's Annapurna Conservation Area (Table 2), scats and scrapes were detected most frequently, scent sprays

and pugmarks least often. Probability of finding signs in Ale et al. (2014) study was highest in spring (10.2 signs/km) and weakest in summer (2.1 signs/ km), which may be due to snow leopard and its prey - blue sheep - moving to higher locations which are less accessible to the observers (Jackson & Hunter 1996; Oli & Rogers 1996). Another possible explanation can be that snow leopard signs are effaced by livestock in summer (Ale et al. 2014). For comparison of effectiveness of sign surveys in different seasons it would be appropriate to conduct sign surveys during summer and spring also in other countries. If such surveys would show that the probability of finding signs is consistently higher in spring, then it might be sufficient to conduct just spring surveys.

For estimates of predator numbers using SLIMS a unified methodology should be used. E.g., for comparison of sign transects between various areas, unit transect lengths should be mutually compared (Ale et al. 2014). It is also necessary to reduce the observation bias. One of the options is that all observers involved obtain the same training to avoid disagreements in what constitutes a snow leopard scrape, which can lead to erroneous results (McCarthy et al. 2008). Environmental conditions (e.g. snow cover) and accessibility of the terrain can also affect the results. With respect to the latter, in Qinghai (China), where snow leopards marked the bases of hills flanking broad valleys where their travel routes were less accessible (Schaller et al. 1988, Ale et al. 2014). Also in the Himalayas, where wide U-shaped valleys and broad ridges are common, it is difficult to find signs of snow leopard (Jackson & Hunter 1996).

### **3.2. *Predator:prey biomass ratio***

Predator-prey models of population dynamics predict that there is a negative feedback between prey and predator biomass (Fuller and Sievert 2001, Carbone and Gittleman 2002). This was indirectly supported for instance in Sary Chat in Kyrgyzstan where the decrease of snow leopards was followed by the increase of ungulate populations (McCarthy et al. 2008). This makes a basis for another method of leopard population size estimation, called predator:prey biomass ratio, when abundance of snow leopard can be estimated from its prey biomass (Fuller and Sievert 2001, Carbone and Gittleman 2002), the latter being estimated using the SLIMS (Jackson & Hunter 1996).

For measuring the numbers of snow leopard prey it is necessary to select a favourable point in each site, from where one does not distract the animals and from where it is possible to localise and determine group size, age and sex of each individual (McCarthy et al. 2008). For observations, it is appropriate to use binoculars and spotting scopes. After this, one calculates the total prey biomass by multiplying the number of observed animals by average prey weight (Fedosenko and Blank 2001). Ungulate biomass per 100 km<sup>2</sup> can then be recalculated to leopard biomass by a simplified conversion factor of 10,000 kg prey for 90 kg of predator (Carbone and Gittleman 2002) and extrapolation to an average weight of snow leopard - 50 kilograms (McCarthy et al. 2008). The predator:prey ratio may be, however, biased due to competition for food with other predator species such as wolves (McCarthy et al. 2008).

Another, more sophisticated method was proposed by Aryal et al. (2014). The maximum number of snow leopards that can be supported by the prey available (its carrying capacity, K) is calculated as

$$K = \frac{A}{ESSR \times AHRS}$$

with:

$$ESSR = \frac{PBY}{PD \times SUF \times BD \times EHD}$$

where:

*A* - area;

*AHRS* - average home range size (about 22.6 km<sup>2</sup>/individual);

*ESSR* - ecological sustainable stocking rate;

*PBY* - prey biomass /snow leopard/year (~548kg/year, 1.5kg/day - Schaller 1977);

*PD* - total prey biomass/km<sup>2</sup>;

*SUF* - safe use factor - the total biomass production of the ecological site that is available for use by animals with the remaining biomass available for ecological sustainability (Alberta Sustainable Resource Development 2004,



Aryal 2007, Aryal et al. 2014); in Nepal, Aryal et al. (2014) used 25% for SUF due to presence of other predators (lynx, red fox, jackal, wolf); it means that snow leopards can consume just 25% of the total sheep population and the rest is available to other predators;

- BD* - birth:death, for instance for blue sheep in Nepal it was presumed as 2:1, according to estimate that 50% of blue sheep die between birth and 2 years of age in Dhorpatan Hunting Reserve (Wegge 1979, Schaller 1977);
- EHD* - environment and human disturbance factor in the habitat (poaching, livestock grazing) responsible for grassland productivity related to prey:predator population; e.g., the Upper Mustang in Nepal has a lower young-to-old male ratio than Lower Mustang due to its lower productivity (Ale et al. 2014); productive grasslands are expected to have a higher proportion of young males while the opposite would be the case with the ungulate population occupying degraded grasslands (Ale et al. 2014).

### **3.3. Genetic analyses**

Genetic analyses of fecal DNA are a promising method of estimating abundance of snow leopard (McCarthy et al. 2008) and with more developed format for scat collection, they would give us better understanding of territoriality or marking behaviour. Genetic analyses are the only method providing information about genetic relationships including source of dispersers (Gese 2001, McCarthy et al. 2008). Their other advantage is that the estimates are not subject to observer bias using specialized equipment and prior training (McCarthy et al. 2008). Genotyping of faeces may generate a higher number of known individuals than visual discrimination based on photographs and provide minimum population estimates. For instance, for Sary Chat, Jangart, and Tomur the estimates based on photos are 3, 5, and 9 individuals respectively, while those based on successful genotypes are 9, 9, and 17 (McCarthy et al. 2008).

Nevertheless, one major disadvantage of these methods is their price (about US\$50–225 for one sample) and also logistics of transportation of faecal material between countries (McCarthy et al. 2008). One of the alternatives how to reduce the costs could be in-country

labs to get the genetic data. Shrestha, who is conducting studies in Nepal, processes samples in a laboratory in Kathmandu and cooperates with his colleagues in Prague for further analyses. It would be more effective if it were possible to export the samples between countries, however.

To utilize genetic analyses for monitoring of snow leopard, first samples must be collected. For instance, McCarthy et al. (2008) in China and Kyrgyzstan received their samples (suspected snow leopard faeces) in the study areas which they determined by SLIMS. Scent pads or hair samples from cheek rubbing (Weaver et al. 2005) could be also used to create a more accurate sampling design. It is important to minimize samples which do not belong to snow leopard by selecting samples according to their shape, location and size. McCarthy et al. (2008) avoided contamination by collecting faecal samples with latex gloves and plastic spoons and then stored in individual 5-ml transport tubes containing 4 ml of 90% ethanol. In general, to avoid errors in scat collection, it is appropriate to obtain also samples of scrapes to increase confidence that it is a snow leopard sign. After collection of samples, DNA extraction is executed in the laboratory and polymerase chain reaction (PCR) in equipment set to low-quantity DNA samples. For DNA extraction it is possible to use stool kits, e.g., the Qiagen stool kit (Qiagen Inc., Valencia, CA) and protocols inclusive negative controls to monitor for contamination. After PCR, the sample is sequenced of an approximately 160–base-pair section of the cytochrome B gene of the mitochondrial DNA control region used by McCarthy et al. (2008). To identify which species deposited each faecal sample, stated primers and formerly published methods are used (Farrell et al. 2000, Onorato et al. 2006). To distinguish individuals of snow leopard, it is appropriate to have as many primers (polymorphic microsatellite loci) as possible. McCarthy et al. (2008) applied 10 polymorphic microsatellite loci to identify individuals of snow leopard.

### **3.4. Camera-traps**

Camera trapping has a wide use ranging from birds to mammals (Cutler and Swann 1999). It is used to estimate presence/absence (Foster and Humphrey 1995, Whitefield 1998), population characteristics (Karanth 1995, Karanth and Nichols 1998) daily activity pattern (Sathyakumar et al. 2011, Pei 1998, Azlan and Sharma 2006), and abundance (Carbone et al. 2001, O'Brien et al. 2003, Rowcliffe et al. 2008) of animals. Camera trapping

is considered as a modern non-invasive method (Mace et al. 1994, Karanth 1995, Karanth and Nichols 1998, Carbone et al. 2001, Mackenzie and Royle 2005) for monitoring of cryptically living animals, such as snow leopard, and for population studies of species whose individuals can be recognized by marks (Sathyakumar et al. 2011, Karanth 1995, Carbone et al. 2001). It is more dependable than other methods when sample sizes are small and species are scarce (Carbone et al. 2001, Sathyakumar et al. 2011). Karanth et al. (2002) and Henschel and Ray (2003) provided detailed methods for using camera traps in tiger (*Panthera tigris*) and leopard (*Panthera pardus*) density estimation. Camera traps are also more suitable for local teams, including protected area staff, so that they can carry out these surveys independently and sustainably over a long term (Alexander et al. 2015).

However, there are also constraints. They are difficult to use in areas with difficult access due to dense vegetation, steepness or too long distance of some locations (Sathyakumar et al. 2011). For instance, high sensitivity of infrared sensor camera units used by Sathyakumar et al. (2011) caused capturing of wind-caused movement of vegetation which caused lot of photos not showing any snow leopard at all. In bad weather, such as high rainfall or extremely low temperature, the cameras sometimes can fail.

We define a “photo event” as any photo or set of photos of a snow leopard at photo-trap site even though it was not possible to identify the individual (McCarthy et al. 2008). Wilson and Anderson (1985) define photo rate as an index of relative abundance (RAI), calculated as the number of photographs of a species divided by the number of trap-days per site (in most cases 100 trap-nights). To obtain more accurate results, it is appropriate to count photos of individuals captured more than once within one hour by the same camera as one photo (Bowkett et al. 2007, Sathyakumar et al. 2011). The number of trap-nights depends on the number of cameras and on the number of days of their operation. For instance, McCarthy et al. (2008) conducted a survey spanning 1,078 to 1,180 trap-nights in each area. In most cases, cameras are oriented towards south or north to reduce the disturbance by solar radiance. In general, the first step in any camera trapping is marking sites of suspected snow leopard trails, e.g., along high, well-defined and narrow ridgelines or valley bottoms or immediately adjacent to frequently scent-sprayed rocks and scrapes (Jackson et al. 2006, Ale et al. 2014). Camera sites are then usually arranged about 2 km from each other in circular pattern, 45-50 cm above the ground, with a 90-second delay

between photographs, as in McCarthy et al. (2008). Infrared sensor is an advantage (Sathyakumar et al. 2011).

### 3.5. Capture-recapture method

The camera capture-recapture method is considered to be a feasible way to estimate densities of individually recognizable animals with large home ranges and low densities, so it is especially suitable for snow leopard (Silver et al. 2004, McCarthy et al. 2008). However, when the densities are very low, this method can be vulnerable to logistical constraints (McCarthy et al. 2008).

Several theories exist of how to create a spatial buffer of potential capture locations to cover the total sampling area (Figure 1, McCarthy et al. 2008). One of them is the mean-maximum-distance-between-recaptures method, formulated on the basis of capture-recapture of small mammal populations (Wilson and Anderson 1985). This theory is often criticised in the literature (McCarthy et al. 2008) and because its dependability is supposed to decrease when trap rate declines and home range size increases (Wilson and Anderson 1985). Another

possibility is to use maximum distance between recaptures for the buffer (O'Brien et al. 2003). The former theory is not well supported in the literature and often criticised (McCarthy et al. 2008), as it is suspected that the dependability decreases when trap rate declines and home range size increases (Wilson and Anderson 1985). A third theory or method is application of the average minimum reported home-range size or average home-range size of the species (Otis et al. 1978). It is not that easy to estimate the size of the home range because it depends on the accessible food biomass. Standard home range size is about 22.6 km<sup>2</sup>/individual. Another issue is that in some areas of snow leopard occurrence data are not available. The Tien Shan Mountains can serve as an example (McCarthy et al. 2008). Home range size of carnivores is often inversely correlated with prey biomass (Fuller and

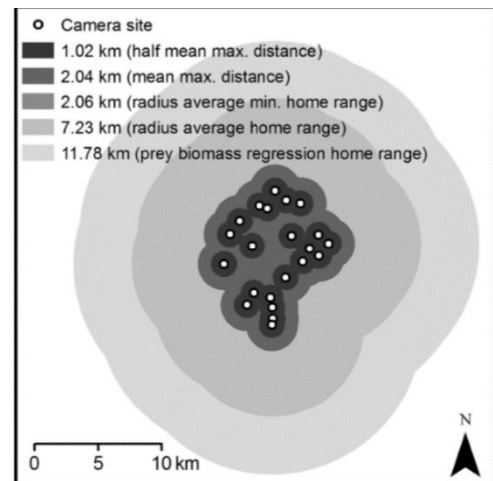


Figure 1. Effective snow leopard study-area buffers around camera-trap sites in the Jangart huting reserve, Kyrgyzstan, 2005 (Source: McCarthy et al. 2008)

Sievert 2001). Therefore, it is appropriate to take into account also ungulate densities (Table 1) and fit the data by a linear regression. McCarthy et al. (2008) calculated the effective study area according to methods which were described above (Figure 1): mean maximum distance moved between recaptures, half mean maximum distance moved in recaptured animals, radius of the average minimum home range or average home range, and radius of the estimated home range from ungulate densities (McCarthy et al. 2008). With choosing one of these methods, the density estimates would be converted considerably (McCarthy et al. 2008). Total coverage of the camera areas and buffer circles effective areas size are utilised for density calculations (McCarthy et al. 2008).

### **3.6. *Biotelemetry (Global Positioning System collaring and radio collaring)***

Biotelemetry is a method for obtaining detailed information about animals which are not easily observed (Jackson et al. 2004). Thanks to biotelemetry, it is possible to better understand movement patterns and factors affecting animal distribution (their home range, patterns of habitat utilization, social organization, and habitat preferences (Schofield et al. 2007, Jackson 1996). This knowledge is necessary in behavioural ecology, protected area management and conservation (Schofield et al. 2007). For snow leopard tracking, radio and satellite transmitters (Global Positioning System, GPS) are used. Both methods are based on receiving data or signals from the transmitter attached to a collar on animal's neck.

For putting on the collar, the animal must be trapped, which requires special skills and can be sometimes dangerous for the animal – therefore both these methods are considered to be invasive (Jackson 1996, Jackson et al. 2004). According to Jackson (1996) the most effective trapping locations are places where vegetation, boulders and other physical structures constrain the movement of snow leopard to a natural trail less than 0.5 m wide, and where abundance of fresh snow leopard scrapes and related signs indicates recent visitation and ongoing marking activity. The immobilized animals are usually weighed, measured, tattooed in the inside of one ear with an identifying number, and fitted with a radio-collar (Jackson 1996).

Telemetry is about one order of magnitude more costly than camera trapping due to manpower needs and equipment (Jackson et al. 2004). Their use is often forbidden along

national borders and other politically sensitive areas, which correspond to an important proportion of snow leopard range areas (Schofield et al. 2007).

Radio tracking is based on transmission of radio frequency pulses by radar systems and measuring the time that reflections of the transmitted signal take to be reflected back (McEwan 1995). The flight time is a measure of the distance from the radar unit to the reflecting objects (McEwan 1995). Highly directional antennas allow such transmissions and signal reflections back to be narrowly focused, so that the direction to such reflective objects can also be estimated (McEwan 1995). Radio telemetry have been used in several parts of Nepal (Oli 1994), India (Chundawat 1989, 1990, 1992), or Mongolia (Schaller et al. 1994). Results of those studies were limited by a small sample size (1-3 individuals) or short periods of monitoring never longer than 3 months (Jackson et al. 2004). First in-depth study using radio telemetry was conducted by Rodney Jackson in Nepal was in 1980's. During 1994-1997, McCarthy et al. (2005) conducted surveys of snow leopard movements and activities on the basis of year-round radio-monitoring in the Altai Mountains of southwestern Mongolia. Home ranges were determined to be at least of 13-11 km<sup>2</sup> in size (McCarthy et al. 2005). Disadvantage of this method is that the mountainous, rocky terrain may affect radio-wave propagation and reception range due to radio-wave attenuation, signal bounce and deflection (Jackson 1996, Amlaner & MacDonald 1980).

Nowadays, the GPS method is used more frequently than radio telemetry due to its greater accuracy. By matching the animal's GPS coordinates with a habitat map using satellite images or aerial photographs and ground-truthing, the researcher is able to determine habitat features or conditions that are most important for feeding, resting or breeding (Jackson et al. 2004). Along with data on average home range size and prey densities, scientists are able to better estimate snow leopard population size and density (Jackson et al. 2004). In 2013 in Mongolia, for the first time ever a mother snow leopard and its wild cubs were located using GPS collars and remote camera traps (Noras 2015). Snow Leopard Trust team collared a female snow leopard and its sub-adult offspring and thanks to that it is possible to monitor the movement of the mother and cub, to observe when and how the young cat becomes independent (Noras 2015).

### **3.7. Comparison of methods used for snow leopard density estimation**

For a rigorous comparison of snow leopard abundance, comparable data from all its habitats are necessary. Such data do not exist. Studies conducted in different snow leopard habitats are not methodologically consistent. The reasons may be objective – e.g., differences between habitats can cause difficulties in data collection, or heterogeneous snow leopard density may not allow using the same methods. In high densities (4-8 individuals/100 km<sup>2</sup>), lower standard errors and long-term research area it is feasible to use the camera capture-recapture method as in the Hemis National Park, India (McCarthy et al. 2008, Jackson et al. 2006). In areas with very low densities and little prior knowledge of snow leopard behaviour, it may prove impossible to attain an adequate capture rate for viable capture–recapture modelling within a short (usually about the 7-weeks) time frame (Karanth et al. 2002, McCarthy et al. 2008). This leads us to a suggestion that the camera capture-recapture method is unreliable, when used in fluctuating home range sizes and very low capture rate (McCarthy et al. 2008). Biotelemetry is also a valuable method to provide detailed information on spatial dynamics of individuals. Nowadays, it is more usual to use GPS collaring rather than radio collaring which is less reliable. However, a huge problem of GPS tracking is its very high price and logistic challenges. From this point of view, usage of this method is possible in countries with higher income or with external support from international organizations.

When determination of the exact densities is not needed, it is possible to use sign surveys or photo rates. According to McCarthy et al. (2008) these two methods are a valid index of snow leopard abundance because of their similarity with genetic results. On the contrary, the estimates resulting from predator:prey biomass ratios and capture-recapture disagreed with other estimates of abundance. For obtaining exact estimates of densities, it would be appropriate to use non-invasive genetic analyses, as mentioned above. Their results are not subject to observer bias, such as other methods may be, for instance erroneous identification of scats. E.g., in the genetic study by Janecka et al. (2008) in Mongolia, up to 60% of all scats that were attributed to snow leopard in fact belonged to red fox (*Vulpes vulpes*). From my point of view, the best way of estimation snow leopard abundance is comparison of sign surveys with the remaining methods (predator:prey biomass ratios, genetic analyses, camera trapping and camera capture-recapture).

#### **4. *Worldwide distribution***

Snow leopard worldwide distribution is restricted to the sub-alpine regions in South and Central Asia and includes 12 countries (Figure 2): China, Bhutan, Nepal, India, Pakistan, Afghanistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, Russia, and Mongolia (McCarthy & Chapron 2013). The total size of its habitat is approximately 1,835,000 km<sup>2</sup> and total population size reaches 4,510 - 7,350 individuals (Fox 1994). According to the range-wide model (Figure 3), the potential area of its distribution is larger: 3,024,728 km<sup>2</sup> (McCarthy & Chapron 2013). This estimate may be overvalued, however, because the range-wide model used only the geographic habitat, neglecting other parameters such as competition, prey distribution or grazing pressure (McCarthy & Chapron 2013).

Results of the range-wide model are presented in Figure 3. Blue-marked areas represent “good” sites with more than 30 degrees slope outside of human disturbance buffers. Violet-marked areas represent “fair” sites of unknown slope or less than 30 degrees or inside of human disturbance buffers. Population densities of snow leopard in “good” areas are larger due to the strong preference of snow leopard to irregular slopes in excess of 40° (McCarthy & Chapron 2013). The 109 protected areas with total size of 276,123 km<sup>2</sup>, identified by Green and Zhimbiev (1997), are marked in red in Figure 3. Table 3 shows estimated areas of snow leopard habitat in km<sup>2</sup>, its estimated populations and densities for individual countries. Table 3 shows all information which I was able to find, nevertheless some data are missing. According to Table 3, the largest population of snow leopard is in China (2,000-2,500 individuals), Mongolia (500-1,000 individuals), Nepal (300-500 individuals) and in India with 200-600 individuals. The greatest density of snow leopard is in Nepal (0.1-10/100 km<sup>2</sup>), Kyrgyzstan (2.35/100 km<sup>2</sup>), and in India (0.5-0.9/100 km<sup>2</sup>). Although the area of snow leopard habitat in Bhutan belongs to the lowest ones (15,000 km<sup>2</sup>), its density there is considerable (1/100 km<sup>2</sup>). It would be appropriate to determine the exact density of snow leopard in Mongolia, Tajikistan, Kazakhstan, Russia, Afghanistan and in Uzbekistan.



#### 4.1. Nepal, India, Bhutan, (Myanmar)

The population of snow leopard in **Nepal** was estimated as 150-300 individuals (Jackson 1979, unpub. data). However, according to a computerized habitat suitability model (Jackson & Ahlborn 1990) the hypothetical population is about 350 to 500 animals located in an area of approximately 30,000 km<sup>2</sup> (Table 3, McCarthy & Chapron 2013). The largest populations occur in the western parts of Nepal: Mustang, Mugu, Dolpo and Humla districts (Jackson 1979). The density of snow leopards in Nepal (0.1-10 individuals/100 km<sup>2</sup>, Table 3) is considered as one of the highest ones in the world. For instance, in Langu Valley in western Nepal, its density is 8-10 individuals/100 km<sup>2</sup> (Jackson & Ahlborn 1989). Nepalese Himalayas are a good habitat for both snow leopard and its major prey species, the blue sheep, on which snow leopard is very dependent (Oli & Rogers 1991, Oli et al. 1993, Lovari et al. 2009, Aryal et al. 2010a).

Locality	Area of habitat (km <sup>2</sup> )	Estimated population	Density of snow leopard (individuals/area)
China	1,100,000	2,000-2,500	1/250-300 km <sup>2</sup> $\div$ 0.3-0.4/100 km <sup>2</sup>
Mongolia	101,000	500-1,000	?
Nepal	30,000	300-500	0.1-10/100 km <sup>2</sup>
India	75,000	200-600	1/110-190 km <sup>2</sup> $\div$ 0.5-0.9/100 km <sup>2</sup>
Pakistan	80,000	200-420	1/250 km <sup>2</sup> $\div$ 0.4/100 km <sup>2</sup>
Tajikistan	100,000	180-220	?
Kazakhstan	71,079	180-200	?
Kyrgyzstan	105,000	150-500	2.35/100 km <sup>2</sup>
Russia	130,000	150-200	?
Bhutan	15,000	100-200	1/100 km <sup>2</sup>
Afghanistan	50,000	100-200	?
Uzbekistan	10,000	20-50	?

Table 3. Distribution, population estimates and density of snow leopard (Source: McCarthy & Chapron 2013, Fox et al. 1991, Jackson and Fox 1997b, Hunter and Jackson (1997), Schaller 1990, Jackson 1992, Chundawat et al. 1988, Annenkov 1990, Zhirjakov 1990, Koshkarev 2000, Koshkarev 1989, Koshkarev 2000, Green 1988, Schaller et al. 1994, McCarthy 2000a, Jackson & Ahlborn 1990, Schaller 1976, Schaller 1977, Hussain 2003, Poyarkov & Subbotin 2002, Bykova et al. 2002, Kreuzberg-Mukhina et al. 2002)



Figure 2. Map of snow leopard range (Source: Jackson et al. 2004)

Location	No. animals monitored	No. days monitored	Mean home-range size	Ungulate density	References
India	1	70	19	3–3.5	Chundawat 1990
Mongolia	1	41	12	1.7–2.3	Schaller et al. 1992
Nepal	3	Winter	19	6.6–10.2	Oli 1994, 1997
Nepal	5	120–450	19.4	4–8	Jackson et al. 1989
Mongolia	4	207	451	0.9	McCarthy et al. 2005

Table 4. Snow leopard home-range estimates ( $\text{km}^2$ ) and related ungulate density ( $\text{no./km}^2$ ) from published studies, India, 1990, Mongolia 1992, 2005, Nepal 1994, 1996, 1997. (Source: McCarthy et al. 2008)

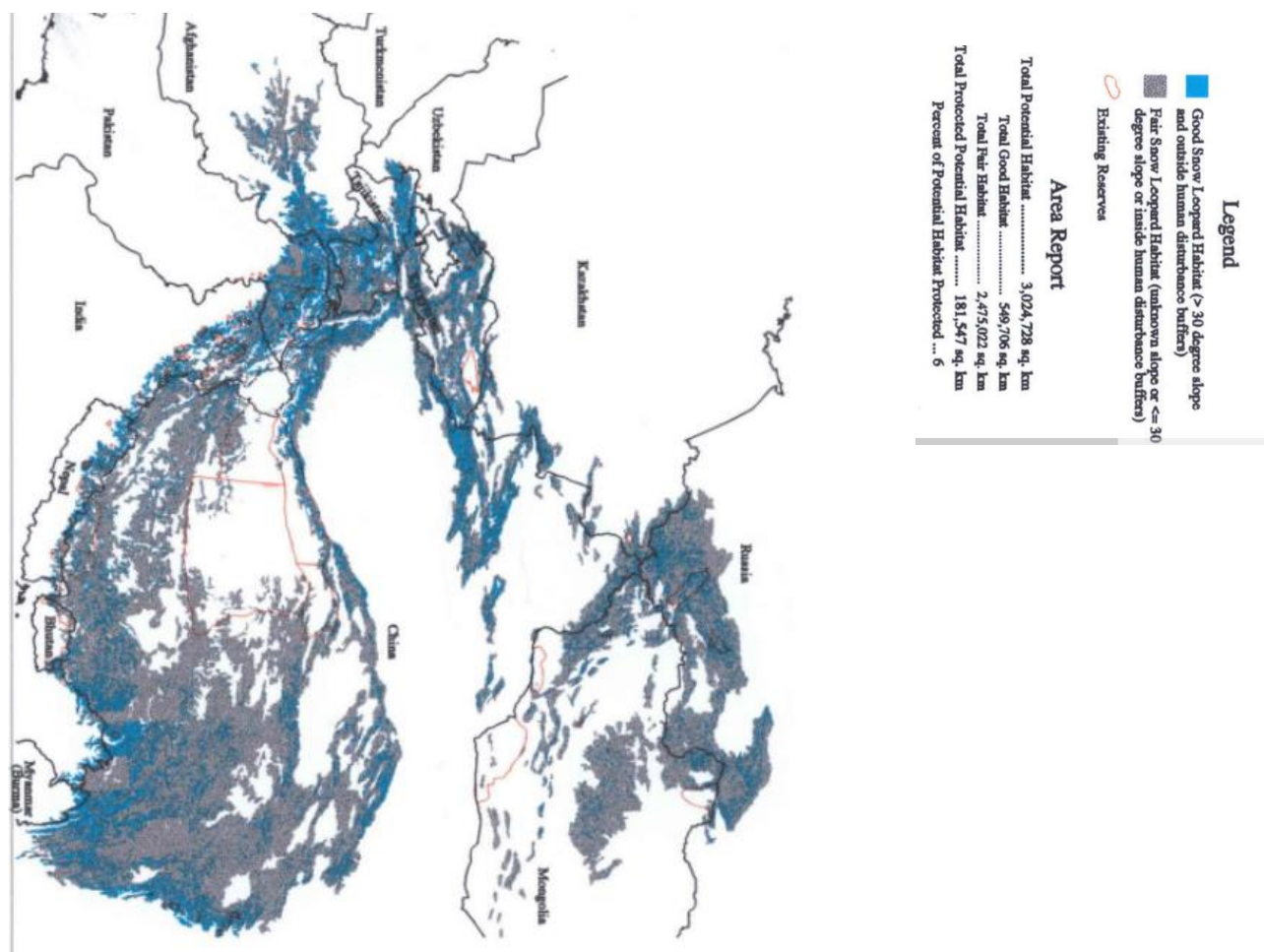


Figure 3. Range wide model of potential snow leopard habitat (Source: McCarthy & Chapron 2013)

Table 4 shows estimations of the numbers of animals monitored, numbers of days monitored, mean home-range size and ungulate density from few countries (India, Nepal and Mongolia). The exact home range size and shape of snow leopard in Nepal is not well known. The home range size of selected five individuals in Nepal ranged from 12 to 39 km<sup>2</sup> (Table 4); the ranges were overlapping each other (McCarthy & Chapron 2013). This home range size is larger than, e.g., in Mongolia with open terrain and less abundant prey than in Nepal (Table 4, 140-400 km<sup>2</sup>/individual).

Jackson and Ahlborn (1990) felt that a large proportion of Nepalese snow leopard population probably lives outside of the country's protected areas, where they were at greater risk from human activities. A study in Nepal indicated that 42–60% of home range use occurred within only 14–23% of the animal's total home area, indicating strong use of

core areas. Core areas were marked significantly more than non-core sites suggesting that social marking plays an important role in spacing individuals (Jackson & Hunter 1996). The core zones in Nepal include Annapurna Conservation Area with approximately 350-500 snow leopards (Jackson & Ahlborn 1990). Almost whole home range of snow leopard is covered by sign survey as mentioned above (Bikram Shrestha, pers. comm.). Sign density (Table 5) recorded in Mustang located in Annapurna Conservation Area is a 5.8 signs/km, thereof 3.7 scrapes/km (Ale 2007). Those results are comparable with results from Mt. Everest (4.5 signs/km, 3.2. scrapes/km). According to sign surveys conducted in Nepal, the highest abundance of snow leopard is in the north-western Nepal such as in the Langu Valley with 36 signs/km. In the north-eastern part of Nepal in Rolwaling the sign density is lower (3.2. signs/km, <1 scrape/km, Ale et al. 2010) than in the northwest. Sign density in Nepal is much higher than in northern Pakistan (2.4 signs/km, Hussain 2003) or in Ladakh, India (2.6 scrapes/km, Fox et al. 2001). According to genetic analyses (Table 5), in the Mt. Everest region 4 cats were detected in 2004-2006 (Lovari et al. 2009), which corresponds to results from camera trappings, provided minimum number of three individuals (capture rate; 2.3 individuals/100 camera trap nights) in Lower Mustang. Even though the sign density in Rolwaling was much lower than in Mt. Everest, an unpublished report based on genotyping revealed occurrence of three snow leopards (Karmacharya et al. 2012). In the upper Mustang region Aryal et al. (2014) estimated biomass of blue sheep to be about 38,925 kg, which can support roughly 19 snow leopards (Table 5, 1.6 snow leopards/100 km<sup>2</sup>).

Charles University in Prague also participates in data collecting on snow leopard in Nepal. In Prague, Pavel Hulva, Dušan Romportl, Tereza Marešová, Pavel Kindlmann and Bikram Shrestha who is collecting data in Nepal, are cooperating. Shrestha et al. use genetic analyses and camera trapping. Shrestha is conducting studies since 2004 in the Sagarmatha National Park in eastern Nepal and from 2010 to 2016 in the Annapurna Conservation Area, specifically in Lower Mustang and Upper Manang (Bikram Shrestha, pers. comm.). For camera trapping, Bushnell model is used to estimate population size in different locations, identify individuals of snow leopard, and determine gender. Although almost whole Nepal is covered by sign surveys, few areas are lacking a detailed survey. To obtain a more exact information about abundance of snow leopard, it would be appropriate to conduct surveys in these areas (e.g., Annapurna Base Camp), where prey is sufficiently abundant to support the presence of snow leopard.

Locality	Sign survey (all signs/km),(scrapes/km)	Genetic analyses (minimum population size)	Predator:prey biomass ratios (snow leopard/100 km <sup>2</sup> )	Photo-capture rates (photos/100 trap nights)	Total carrying capacity (total number, snow leopards/km <sup>2</sup> )	Photo capture-recapture (snow leopard/100 km <sup>2</sup> , n= identified s.l./photo)
Mustang region, Nepal	5.8, 3.7		1.6	2.3	19, 1.6/km <sup>2</sup>	
Mt. Everest, Nepal	4.5, 3.2	4				
Langu Valley, Nepal	3.6 all signs./km					
Rolwaling, Nepal	3.2, <1					
northern Pakistan	2.4 all signs/km					
Tomur, China		9	1.1	2.37		0.74 (n = 5/6)
Zongjia Township, China		11				
Nuimuhong Township, China		5				
Suojia Township, China		5				
Qilianshan Nature Reserve of Gansu Province, China						3.52
Kunlun Mountains, China	0.16, 0.13					
Sary Chat, Kyrgyzstan		3	8.7	0.09		0.15 (n=1/1)
Jangart, Kyrgyzstan		5	1.0	0.93		0.87 (n = 4/13)
Hemis NP, India				8.9, 5.6		
Khangchendzonga BR, India				0,257 ± 0.16		

Table 5. Methods and results of methods used for estimation of snow leopard

Estimated population size of snow leopard in **India** is about 200-600 individuals in an area of 75,000 km<sup>2</sup> (Table 3, Chundawat et al. 1988, Fox et al. 1991). Counts of snow leopards are derived from an average density of one animal/110 km<sup>2</sup> for good habitat along

the north slopes of the Himalaya with area of 30,000 km<sup>2</sup> and one animal/190 km<sup>2</sup> for lower quality habitat along the southern slopes of Himalaya with area of 22,000 km<sup>2</sup> (Table 3, Fox et al. 1991). Chundawat et al. (1988) suggested Ladakh as a core area of snow leopard (72,000 km<sup>2</sup>). Snow leopard may occur in the following protected areas: Himachal Pradesh State (e.g., Pin Valley National Park, Khokhan Wildlife Sanctuary or Rupin Bhaba Wildlife Sanctuary), Uttarakhand State (e.g., Nanda Devi National Park, Nanda Devi National Park or Yamunotri Wildlife Sanctuary), Arunachal Pradesh State (e.g., Dibang Valley), Sikkim State (e.g., Khangchendzonga National Park, Dzongri Wildlife Sanctuary, and Tolung Wildlife Sanctuary) and Jammu and Kashmir State with 12 areas (e.g., Hemis National Park, Dachigam National Park or Lunghag Wildlife Sanctuary). The presence of snow leopard in many of these areas is uncertain (McCarthy & Chapron 2013). Northwest India hosts approximately 400 snow leopards with largest densities in the trans-Himalayan ranges in Ladakh. Therefore, new parks and reserves are being established there (Fox et al. 1991). The only one protected area where the density of snow leopard is known is the Hemis National Park of Ladakh region located in the Jammu and Kashmir State. Mallon and Bacha (1989) estimated 75-120 snow leopards in a 1,200 km<sup>2</sup> area to be living there. Jackson et al. (2006) reported 66 and 49 capture events (capture success 8.9 and 5.6 per 100 trap-nights, Table 5) in two consecutive years of 2003 and 2004 in the Hemis National Park. In the Khangchendzonga Biosphere Reserve in the eastern Himalayan region (Sikkim), Sathyakumar et al. (2011) conducted a first survey to obtain basic information about abundance of mammal species including snow leopard. They proved the presence of snow leopard by photo capture method, scat/dung method, tracking, and information from locals. Photo capture rate of snow leopard was 0.257 photos/100 trap nights (Table 5, Sathyakumar et al. 2011). Sathyakumar et al. (2011) recommend to conduct surveys also in other watersheds of the Khangchendzonga BR. In India, it is necessary to cover whole area by sign surveys and after that also conduct detailed studies.

In northern **Bhutan**, along the high Himalayas, in accord with the area-based estimates, the confirmed presence of snow leopard is about 100-200 individuals (Table 3, Fox 1989). The density of snow leopard is assumed to be 1/100 km<sup>2</sup>. The suitable habitats are above 3,000 m in an area of about 15,000 km<sup>2</sup> (Fox 1994). In Jigme Dorje National Park, sign surveys were conducted, suggesting a lower occurrence of snow leopards than in



adjacent Shey Phoksundo National Park in Nepal, although there is a larger abundance of its prey in the former (Jackson and Fox 1997b, Jackson et al. 2000). In a part of the protected area (Torsa Strict Nature Reserve, Kulong Chhu Wildlife Sanctuary, Sakteng Wildlife Sanctuary) the occurrence of snow leopard is still not confirmed.

#### 4.2. China and the former Soviet Union

**China**, the largest state where snow leopard occurs, contains as much as 60% of its potential habitat: about 1,824,316 km<sup>2</sup> (Figure 3, Hunter and Jackson 1997, McCarthy & Chapron 2013). Area of snow leopard presence is estimated as 1,100,000 km<sup>2</sup> with approximately 2,000-2,500 individuals (Table 3, Fox 1994). Due to irregular distribution of its prey, the mean density is 1 snow leopard/250-300 km<sup>2</sup> (Table 3, McCarthy & Chapron 2013).

Snow leopard habitat is located in six provinces in China (Qinghai, Gansu, Sichuan, Yunnan, Xinjiang and Xizang or Tibet), in the seventh one (Inner Mongolia) it is nearly extinct (McCarthy & Chapron 2013). In almost every province, there is a lack of status surveys, such as in Sichuan Province, Yunnan Province or in Tibet Autonomous Region (TAR). In the TAR, in several sites there is a reasonable abundance of blue sheep. Areas with the highest priority for status surveys are the Nayainqentanglha, Taniantaweng and Ningjing Shan mountains in eastern and south-eastern Tibet, and

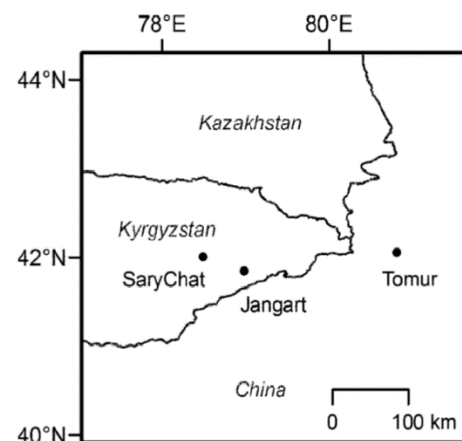


Figure 4. Study area diagram depicting 3 snow leopard camera capture-recapture study sites, Sary Chat, Jangart and Tomur, in the Tien Shan Mountains of Kyrgyzstan and China, 2005 (Source: McCarthy et al 2008)

along with western Nepal, the mountains bordering Uttar Pradesh in India, and the Nganlang Kangri mountains bordering Ladakh (McCarthy & Chapron 2013). Snow leopard occurrence is expected especially in the northern slopes of the Himalaya close to border with Nepal and mountain ranges bisecting the Tibetan Plateau (McCarthy & Chapron 2013). Jackson (1994a) reported up to 100 cats in the Qomolangma Nature Preserve, a 33,910 km<sup>2</sup> area along the main Himalayan and Nepalese border, centered by Mt. Everest. In the area including Sanjiangyuan National Nature Reserve (Qinghai Province), Qiangtang National Nature Reserve (TAR) and Nanshan area (Danghe, Gansu Province) 89 samples were identified as snow leopard and they belonged to 48 individuals (Zhou et al. 2014). In the Tomur

National Nature Reserve (Figure 4) in Xinjiang Autonomous Region, 20 SLIMS sign surveys were accomplished by McCarthy et al. (2008). By counting the snow leopard's prey, ibex and argali, the snow leopard potential density was estimated to be 1.1 snow leopards/100 km<sup>2</sup> (Table 5, McCarthy et al. 2008). Photo-capture rates in Tomur were 2.37 photos/100 trap-nights (Table 5). According to the results of photo capture-recapture method (0.74 individuals/100 km<sup>2</sup>, n = 5/6), it is estimated to be about 6 individuals of snow leopard occurring in Tomur, while according to genetic analyses it was more: at least 9 individuals (McCarthy et al. 2008). Home range of snow leopard in the Qinghai Province is highly fragmented (Liao 1994). Zhang et al. (2009) identified 11, 5 and 5 (Table 5) snow leopards by genetic analyses in Zongjia Township (ZJ) and Nuomuhong Township (NMH) in Dulan County, and Suojia Township (SJ) in Zhiduo County, respectively.

Apart of those areas with occurrence of snow leopard, Schaller et al. (2008) identified three “hotspots” in Qinghai Province: North Zadoi, South Zadoi and Yushe, where the density of snow leopard was estimated to be 1 individual per 25-35 km<sup>2</sup>. In adjacent Gansu Province northeast from Qinghai Province, 17-19 individuals were identified by camera capture-recapture method. In total, 251 snow leopard captures were recorded over the 7,133 trap-days representing on average 3.52 captures per 100 trap-days (Table 5, Alexander et al. 2016).

The Gouli Region (Figure 5) also in Qinghai Province is considered as one of the core zones of snow leopard in China. Sign surveys were conducted there in transects with total length of approximately 440 km and 72 snow leopard signs and 60 scrapes signs were detected (Xu et al. 2008), which gives 0.16 signs/km and 0.13 scrapes signs/km (Table 5). As mentioned above, in China, information on snow leopard abundance is lacking and results of some studies conducted there are not consistent with those from other countries.



Figure 5. Survey area in the Gouli Region in East Burhanbuda Mountain, Kunlun Mountains, China, indicating the locations of leopard signs and camera traps (Source: McCarthy et al. 2008)

Before the breakup of the USSR (1990), the USSR was said to support 1,000 to 2,000 snow leopards (Braden 1982, Bannikov 1984). Most of the population (75%) lived in Kyrgyzstan and Tajikistan (Koshkarev & Vyrypaev 2000). According to these authors and Bannikov (1984), there were 150 - 200 cats in the Russian Union Republic, 100 in Uzbekistan



and 180-200 in Kazakhstan making a total of about 2,000 individuals. Koshkarev (1989) estimated the population of the Tien Shan and Dzhungarsky Alatau to be about 400-500 individuals. After the disintegration of the USSR, the populations in Kazakhstan and Kyrgyzstan decreased by at least 50% due to poaching of snow leopards and ungulates (McCarthy & Chapron 2013). The current legal and management status of many reserves is unknown.

Presence of snow leopard in **Russia** (Table 3, Table 6, Figure 2) is reported in the Altai and Sayan ranges on the border with the People's Republic of Mongolia, and in southern Siberia including Tuvan and Buryat mountain ranges (Paltsyn et al. 2012). The mean density in the Altai Mountains is estimated as 0.75 - 1.5/100 km<sup>2</sup> with approximately 40 individuals (Sopin 1977). In accordance with Table 5, in the Chikhachev Ridge located in the Altai

Location	Habitat area, km <sup>2</sup>	Estimate population (# of animals)	Notes
Chikhachev Ridge	1000	5-7	Total population of this transboundary group, including Mongolia, is 10-15 animals
Tsagan-Shibetu Ridge, southern Shapshalsky Ridge, western side of Western Tannu-Ola Ridge	2500	15-18	Total population of this transboundary group, including Mongolia, is 20-25 animals
Sayano-Shushensky Nature Reserve, its buffer zone, and adjacent parts of Khemchiksky and Kurtushubinsky Ridges	No more than 200-500	9-10	
Sengelen Ridge	2000	7-10	
Okinsky and Tunkinsky Ridges, possibly	5000-6000	15-20	This area requires additional research
<b>TOTAL:</b>	<b>6000</b> (possibly 11 000-12000 if Okinsky & Tunkinsky Ridges are included)	<b>36-45</b> (possibly 50-65 if Okinsky and Tunkinsky Ridge populations are included)	

Table 6. Area of existing snow leopard populations in Russia (Source: Paltsyn et al. 2012)

Republic, Tuva Republic, and Mongolia, about 5-7 snow leopards occur, or 10-15 if

we include also group of snow leopards in Mongolia. Snow leopard population size in the Sayan region is about 20-30 individuals (Koshkarev 1996) and in Sayano-Shushensky Nature Reserve in the Sayan region about 9-10 snow leopards (Table 6). In southern Siberia, snow leopard possibly occurs in Okinsky and Tunkinsky Ridges (Table 6, Paltsyn et al. 2012). Smirnov et al. (1990) estimated that about 80 snow leopards resided in southern Siberia including animals that wandered into the Mongolian territory. As mentioned in Table 5, this area requires additional research. In general, in Russia detailed data are also lacking or outdated.

In **Kyrgyzstan**, there is still not enough published wildlife research of the post-Soviet distribution and status of many species (McCarthy et al. 2010). On the other hand, the Government of the Kyrgyz Republic has increased the enforcement and development of protected areas (Dexel 2002, Chapron 2005). Snow leopards occur in the Talasskiy Alatau

and Ferganskiy mountains, as well as in the Tien Shan bordering China and Kazakhstan (Figure 2, Braden 1982, Koshkarev 1989). Koshkarev (1989) estimated population of 113-157 with average density of 2.35 snow leopards/100 km<sup>2</sup> (Table 3). McCarthy et al. (2008) conducted surveys of snow leopard abundance in the Jangart and Sary Chat Ertash in the Tien Shan Mountains of eastern Kyrgyzstan (Table 5). Sixteen sign surveys were accomplished in the Sary Chat with total transect length of 8.2 km, 13 surveys with 8.6 km transect length in the Jangart. The population size of snow leopard in Jangart was estimated as 7 individuals. According to photo capture-recapture outcomes it was evaluated 0.15 (n = 1 identified individual/1 photo) in the Sary Chat and 0.87 (n= 4/13) in the Jangart (Table 5). By counting the snow leopard's, prey: ibex and argali, snow leopard potential density was estimated as 8.7 snow leopards/100 km<sup>2</sup> in Sary Chat and 1.0 snow leopard/100 km<sup>2</sup> in Jangart.

According to Hunter and Jackson (1997), the estimated size of potential snow leopard habitat in **Kazakhstan** is 71,079 km<sup>2</sup>. Its estimated population size is approximately 180-200 individuals (Table 3, Annenkov 1990, Zhirjakov 1990). In the south of Kazakhstan, snow leopards occur along the Khigizskiy Range and Tasskiy Alatau bordering Kyrgystan, in the Sarytau Mountains near Alma Ata, and bordering China in the Dzungarsky Alatau. (McCarthy & Chapron 2013). According to Zhirjakov (1990) Zailiskiy Alatau or northern Tien Shan has about 20 leopards. The presence of snow leopard in protected areas is confirmed in the Aksu Dzhabagliy State Reserve and Alma Atinskiy Nature Reserve (McCarthy & Chapron 2013).

In **Tajikistan**, data about the current status and distribution of snow leopard are lacking. Snow leopards are said to occur in the central and western parts in the Zeravshanskiy, Gissarskiy, Karateginskiy, and Petr Pervyi mountains, and in the Hazratishog and Darvaskiy Mountains, and in the Gorno-Badakhshansk area, including the Pamirs (McCarthy & Chapron 2013). Bykova et al. (2002) estimated the total amount of 180-220 snow leopards (Table 3). Occurrence of snow leopard is confirmed mainly in reserves and protected areas such as in the Great Pamir National Park (Hunter and Jackson 1997), Ramit State Reserve, Dashti-Dzhumskiy Reserve (Sokov 1990), Iskanderskul'skiy lake reserve, Muzkul'skiy, Pamisskiy, and Sangvorskiy Zakazniki reserves (McCarthy & Chapron 2013). In 2003, Rodney Jackson conducted survey to examine the possibilities of promoting wildlife conservation in Tajikistan. He trained local staff and herders in basic survey methods based on transects to monitor snow leopards and Marco Polo sheep (Jackson et al. 2004).

**Uzbekistan** formed the far western edge of the snow leopard's home range. Snow leopards were reported from the Turkestanskiy, Chatkalskiy and Gissarskiy ranges bordering Tajikistan and Kyrgyzstan (Braden 1982) with the total population estimated as 50 animals (Sludskiy 1973, cited in Braden 1982). Recent data from Kreuzberg-Mukhina et al. (2002) estimated the population of snow leopard as about 20-50 in the area of 10,000 km<sup>2</sup> (Table 3). As in Tajikistan, snow leopard presence is confirmed in protected areas, for instance in Zaaminskiy State Reserve, Uzbek National Park, Gissarskiy State Reserve, and the Chatkal'skiy State Reserve (McCarthy & Chapron 2013).

#### **4.3. *Pakistan, Afghanistan and Mongolia***

The potential snow leopard habitat in **Pakistan** covers 80,000 km<sup>2</sup> (Table 3, Fox 1994) with about 200-420 individuals (Schaller 1977, Hussain 2003). Assuming a mean density of 1 snow leopard/250 km<sup>2</sup>, the total amount of snow leopards would be approximately 320 individuals (McCarthy & Chapron 2013). Its occurrence is verified in the Northwest Frontier Province's Chitral District and in the Karakorum Range of the Northern Areas in the Gilgit, Hunza and Baltistan districts (McCarthy & Chapron 2013). Hussain (2003) conducted a surveys in the Baltistan district between 1998 and 2001 and estimated that approximately 36-50 snow leopards are living there. With respect to availability of its prey and suitable habitat he suggested occurrence of 90-120 snow leopards in the whole Baltistan. Its presence in Azad Kashmir Province remains unconfirmed (Roberts 1977). Snow leopard occurrence is confirmed in the following protected areas: North-West Frontier Province (Chitral Gol National Park, Agram Besti Game Reserve, Goleen Gol Game Reserve, Gahriat Gol Game Reserve) and northern parts (Khunjerab National Park, Baltistan Wildlife Sanctuary, Kargah Wildlife Sanctuary, Nazbar Nallah Game Reserve). In many protected areas, potential habitats for snow leopard were located, but not verified: Parit Gol Game Reserve, Tirichmir and Qashqar Conservancies, Kilik/ Mintaka Game Reserve, Naz/Ghoro Game Reserve, Sherquillah Game Reserve, Askor Nullah Game Reserve, Astore Wildlife Sanctuary, Chassi/Bowshdar Game Reserve, Danyor Nallah Game Reserve, Pakora Game Reserve, Machiara National Park, and Ghamot Game Reserve (McCarthy & Chapron 2013). Snow leopard presence is likely also in the Nanga Parbat Conservancy (McCarthy & Chapron 2013).

The population size of snow leopard in **Afghanistan** still has not been determined. The estimations of area of potential habitat in Afghanistan slightly differ from each other. Fox (1989) estimated 80,000 km<sup>2</sup>, later also Fox (1994) 50,000 km<sup>2</sup>, and subsequently Hunter and Jackson (1997) suggested 117,653 km<sup>2</sup> (Table 3). Snow leopard occurrence was confirmed in the Hindu Kush and Pamir mountains of north-eastern Afghanistan (Habibi 1977, Petocz 1978, Sayer 1980). In Zedak in the southern part of Badakhshan snow leopard occurrence was also reported (McCarthy & Chapron 2013). Due to a long history of many wars in Afghanistan, there wildlife laws are not enforced there (McCarthy & Chapron 2013). The actual status of snow leopard abundance in many locations is not known (McCarthy & Chapron 2013). The latest information about occurrence of snow leopard are from Wakhan District of Badakhshan where the Wildlife Conservation Society (WCS) and the National Environmental protection Agency have installed remote camera traps in 2009 and recorded over 1300 images of snow leopard at 20 sites (Noras 2015). Three individuals were captured and equipped with satellite collars in 2012. Thanks to the confirmation of presence of snow leopard in that area, the whole of Wakhan District was declared a National park in 2014 with area of 10,000 km<sup>2</sup> (Noras 2015).

**Mongolia** is a state with the second largest population of snow leopard after China (Noras 2015), estimated as 500-1,000 individuals (Green 1988) in the area of approximately 101,000 km<sup>2</sup> (Table 3, Figure 2, Schaller et al. 1994, McCarthy, 2000). It occurs in at least 10 protected areas: the Transaltay Gobi Strictly Protected Area or SPA, Khokh Serkh SPA, Otgontenger SPA, Tsagaan Shuvuut SPA, Turgen Uul SPA, Gobi Gurvansaikhan National Conservation Park, Altai Tavaan Bogd NCP, The Burhan Buudai Nature Reserve, Alag Khaikhan Nature Reserve and Eej Uul National Monuments (McCarthy & Chapron 2013). The main populations are said to occur in the Altay and Transaltay Gobi mountain ranges, with smaller populations in the Khangai, Hanhohiy Uul and Harkhyra Uul ranges (McCarthy & Chapron 2013). Bold and Dorzhzunduy (1976) estimated 170-230 snow leopard in the southern Gobi region of Mongolia. During 1994-1997 McCarthy et al. (2005) conducted surveys of snow leopard movements and activities on the basis of year-round radio-monitoring in the Altai Mountains of southwestern Mongolia. Home ranges were shown by standard telemetry techniques to be at least of 13-11 km<sup>2</sup> (McCarthy et al. 2005). In the area of Burhan Budai of the Altay, Schaller et al. (1994) found signs of at least 10 cats within 200

km<sup>2</sup>. This density is one of the highest densities estimated in whole of its habitat. From 2008, the Snow Leopard Trust (SLT) and Panthera, in co-operation with the Mongolian government, started a program lasting 10 years. Hitherto they have captured and radio collared 20 individuals. To date, in the Altai Mountains conservation programs involve more than 400 herder families (Noras 2015). In 2014 in Tsagaan Shuvuut Strictly Protected Areas, at a transboundary site in Mongolia and Russia a Mongolian-Russian team, headed by Dr. B. Munkhtsog captured a female snow leopard and put it the North star satellite collar provided by Snow Leopard Conservancy.

## **5. Conservation of snow leopard**

Conservation of snow leopard, is a very complex problem because of its rugged habitat, large home range, and conflict with humans (Li 2013). Below is a list of some possible ways of its protection, including functional legislation, international cooperation, financial support, education and awareness.

### **5.1. Legislation**

Legislation relating to conservation of snow leopard is based on designation of nature reserves by governments and supporting programs led by nongovernmental organizations (McCarthy & Chapron 2003, Mishra et al. 2003). However, their abilities are limited (Li 2013). There is a little information on the current management status of protected areas or their role in sustaining snow leopard populations (Fox 1994, Green 1992, 1994, Green and Zhimbiev 1997). To date, the areas of snow leopard habitat covered by nature reserves are just 0.3–27% in 11 of 12 range countries (Li 2013). The only exception is Bhutan with 57% area of snow leopard home range protected (Hunter & Jackson 1997).

To preclude the threats to snow leopard such as poaching and illegal trade, it is necessary to implement a functional legislative and conservation policies to effectively prevent the hunting, killing, possession, sale and trade of snow leopards including all body parts and derivatives at local regional and national levels (Theile 2003, Aryal et al. 2013). It would help to offer legal assistance and advice to governments to consolidate penalties to people who break the law, and also to consider "whistle-blower" policies to provide incentives to report illegal activities (Theile 2003, Aryal et al. 2013). Theile (2003) also recommended to set up "antipoaching" teams, which would monitor main markets and trade centres, and to reveal the illegal killing. For better understanding of the factors affecting the effectiveness of protected areas for diversity conservation, long-term and detailed research, evaluation of the interactions between populations outside and inside of protected areas are needed (Gaston et al 2008).

Support from government of each state is necessary for a successful conservation management. Four countries already have national action plans: Nepal, Pakistan, Mongolia and Russia (McCarthy et al. 2003). The government of India initiated the Project Snow Leopard (PSL), a national governmental program, on 20 January, 2009. The goal of that project is to conserve snow leopard together with other species living in the high-altitude of Himalayas including five states: Jammu & Kashmir, Himachal Pradesh, Uttarakhan, Sikkim and Arunachal Pradesh (Rajput 2009). The PSL is based on knowledge-based adaptive wildlife management policies and actions, law enforcement, and promotion of awareness and education for wildlife conservation (Rajput 2009). This concept of the PSL was constructed at a national conference in Ladakh 2006 thanks to the collaboration of the International Snow Leopard Trust (ISLT), the Nature Conservation Foundation (NCF), the State Governments, the Ministry of Environment and Forests (Government of India), Wildlife Institute of India (WII), the Snow Leopard Network, local communities and certain NGOs (Rajput 2009).

## **5.2. *International cooperation***

Snow leopard home range is located across 12 countries in South and Central Asia. Therefore, cooperation of all those states is necessary, using internationally valid acts such as Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) which sets regulations on export or import of animals or their body parts (Nowell 2007). Protected areas play an important role in sustaining the overall snow leopard population because home range of snow leopard encompasses areas that constitute international borders (McCarthy & Chapron 2003). The Snow Leopard Network (SLN 2008) unifies individuals and organizations such as the Snow Leopard Conservancy or the International Snow Leopard Trust. The SLN function is to coordinate, cooperate and share information. International conferences try to identify locations for snow leopard conservation, named Snow Leopard Conservation Units, and to provide a framework for the development of national action plans (Jackson et al. 2008). Recently, e.g., an International Conference on Range-wide Conservation Planning for Snow Leopards was held in Beijing, China in March 2008. Another function of international society, such as World Wildlife Fund (WWF), is to

secure transparent and clear funding for compensatory programmes with governments, for instance with the Nepalese government (Ikeda 2004).

Snow leopard is legally protected from hunting by national legislation across most of its 12 range states (McCarthy et al. 2003). Afghanistan has recently afforded the snow leopard legal protection, after listing the species on the country's first Protected Species List in 2009. This act bans all hunting and trading of snow leopards within Afghanistan. Except of Tajikistan, the rest of the countries are signatory to the CITES agreement (Jackson 2014).

### **5.3. Education & Awareness**

It is important to educate and increase awareness of snow leopard conservation among local communities, national governments and international audience (Jackson et al. 2008). The effectiveness of conservation management is increased by using community-based program involving local people such as livestock herders, trekking guides, farmers, and former hunters (Sathyakumar et al. 2011). Various ways how to support cultural, social and religious beliefs of locals exist such as education of the public by monks in monasteries or involving locals to programs related to some study, e.g., measurement of climate change (Jackson et al. 2008).

The Snow Leopard Survival Strategy (McCarthy et al. 2003) may include grazing management practices which would diminish impacts on native wildlife (e.g. large ungulates) and also support husbandry practices which would reduce livestock vulnerability to snow leopard predation and improve efficiency and yield (Jackson et al. 2008). As mentioned above, herders of small and medium-sized livestock are notably vulnerable to damage. On this count, there may be special custody of them. Comprehension of the carrying capacity (based on the distribution and the population structure) for predators such as snow leopard will simplify the management of human-wildlife conflict (Aryal et al. 2014). One of the major issues is to protect prey population (e.g. blue sheep) as a resource base for snow leopards to avoid larger predation of livestock and enhancement of human-predator conflict (Aryal et al. 2014). It would also be appropriate to provide a legal mechanism for herders how to remove individual snow leopards liable for repeated livestock depredations (McCarthy & Chapron 2003). In prior studies, physical precautions, such as installation of predator-proof livestock corrals or guard dogs or formation of core areas, for snow leopard conservation were recommended (Jackson & Hunter 1996, McCarthy & Chapron 2003). Another issue is to



decrease suspicions of herders that snow leopard abundance will be unduly in the future, by more adaptable conservation policies which would be better compromise between livestock rearing and wildlife protection (Ikeda 2004).

One of the ways how to protect snow leopard is a monastery-based conservation. Along research conducted in the Sanjiangyuan region in China's Qinghai Province, or Mustang in Nepal, Buddhist monasteries play an important role in snow leopard conservation (Li 2013, Ale et al. 2014). This method may be very efficient. By spreading this method to other Tibetan Buddhist regions, it would cover about 80% of snow leopard habitat (Li 2013). It would be possible to decrease killing of snow leopard by adherence to Buddhist tenets such as respect, love, and compassion for all living beings. In accordance to survey, the 336 monasteries located the Sanjiangyuan region may protect more snow leopard habitat (8,342 km<sup>2</sup>) through social norms and active patrols than the nature reserve's core zones (Li 2013).

Climate change is another serious issue, as mentioned above (Chapter 2.4. Climate change). It is important to implement strategies of mitigation and adaptation to conservation management at the local level to hinder climate changes (Jackson et al. 2008). The strategy may include plantations on private land and local areas, use of solar energy for cooking and heating, spread of native grass seeding around the area, development of water holes in areas where long distances need to be covered, storage of rainfall water for agriculture, construction of reservoirs for winter and times of water shortage, control of poaching, and continued monitoring of the distribution and shift of trees (Aryal et al. 2013). For conservation planning, bioclimatic models, used to predict persistence of species populations and habitats due to climatic change, are impractical because their reliability and scope are limited (Heikkinen et al. 2006, Lawler et al. 2006). Therefore, usage of individual-species climate models as guidelines for climate-integrated conservation planning may be more appropriate. They are more reliable than community-based or assemblage models (Hannah et al. 2002a., Pearson and Dawson 2003, Thuiller 2007).

#### **5.4. *Financial support***

For efficient conservation management it is essential to entirely understand the economic conditions of local herders and to find how to avoid conflicts between wildlife

conservation and livestock rearing in countries with low income (Ikeda 2004). It is necessary to obtain detailed ecological and socio-economic information to design a system which would successfully function (Mishra et al. 2003). Except of the Annapurna Conservation Area and the Spiti Region of Himachal Pradesh in India, where these surveys were conducted by Oli et al. (1994), Jackson et al. (1996), and Mishra (1997), there is a lack of such data in the rest of snow leopard habitat (Ikeda 2004).

One of the options how to improve the compensatory mechanism, is to involve herders in ecotourism activities (Schellhorn & Simmons 2000), as it works in Baltistan (in Tibet) and Pakistan (Hussain 2000). This possibility in Nepal may struggle because of unstable situation in the country and due to lack of foreign trekkers (Hussain 2000). Other alternative for financial incentives recommended by the Snow Leopard Survival Strategy (McCarthy et al. 2003) may be cottage industry, e.g., village-made handicrafts, or well-structured ungulate trophy hunting program (Mishra et al. 2003, Jackson et al. 2008). This innovative program was already initiated in Kyrgyzstan (McCarthy et al. 2010, Mishra et al. 2003).

## **6. Conclusions**

In this thesis, I have summarized distribution of snow leopard in each country of its occurrence with reference to methods of estimates where the information was available (Table 3 and 5). Despite all efforts, it appeared impossible to compare results obtained by using different methods, mainly due to inconsistency of results. According to my survey, the largest population of snow leopard is in China (2,000-2,500 individuals), Mongolia (500-1,000 individuals), Nepal (300-500 individuals) and in India with 200-600 individuals (Table 3). On the other hand, the smallest populations of snow leopard were estimated in Russia (150-200), Bhutan (100-200), Afghanistan (100-200), and in Uzbekistan (20-50). According to the available data, the greatest density of snow leopard per 100 km<sup>2</sup> of suitable habitat is in Nepal (0.1-10/100 km<sup>2</sup>), Kyrgyzstan (2.35/100 km<sup>2</sup>), and in India (0.5-0.9/100 km<sup>2</sup>). Although the area of habitat in Bhutan belongs to the lowest ones (15,000 km<sup>2</sup>), the density of snow leopard is considerable (1/100 km<sup>2</sup>). It would be good to determine the exact density of snow leopard in Mongolia, Tajikistan, Kazakhstan, Russia, Afghanistan and in Uzbekistan.

In chapter 3.7., I compared usage of different methods of estimation of snow leopard abundance. From my point of view, the best way is first to perform sign surveys, which can serve as a pilot study for choosing appropriate method(s) and then compare the results of all methods used with the rest of methods (predator:prey biomass ratios, genetic analyses, camera trapping and camera capture-recapture methods).

I have analysed general threats to snow leopards with reference to various regions. My study revealed that the main threats to the snow leopard are conflict with locals (human-snow leopard conflict), lack of conservation capacity, illegal trade, awareness and policy, and climate change. Killing of snow leopard in indemnification for livestock depredation and reduction of natural prey is inherently challenging in the Himalayan region (India, Nepal, Bhutan, Tibetan Plateau and other southern China), Karakorum and Hindu Kush (southwest China, Pakistan and Afghanistan). The issue of military conflict is problematic in the Himalayan region and Commonwealth of Independent States and western China.

To improve the conservation management to increase the likelihood of survival of snow leopard, it would be useful to obtain detailed information about current management

status and role in sustaining snow leopard populations in protected areas where it is now unknown.

Introduction of “antipoaching” teams may decrease the poaching and illegal trade in areas of snow leopard presence. To improve international cooperation, the signature of Tajikistan, as the last non-signatory country, is needed to the CITES agreement. Also, the trans-boundary cooperation should be modified in almost every location of snow leopard range to decrease logistic constraints, e.g. with transportation of samples for genetic analyses, or to build more laboratories in each country. Action plans now exist only in Nepal, Pakistan, Mongolia and Russia. It would be advisable to create national action plans or governmental programs also in the remaining countries.

According to my survey, the most functional conservation management includes community-based programs involving local people, such as monastery-based conservation, protecting snow leopard through social norms and active patrols. Thus it may be effective to spread this method to other Tibetan Buddhist regions. To improve the financial aspect of conservation management of snow leopard, it would be suitable to obtain detailed surveys of economic conditions of local herders (up to now are available just in Annapurna Conservation Area in Nepal and Spiti Region in Himachal Pradesh in India) and estimate the monetary value of livestock damage to estimate the proper amount of compensation. The improvement of procedure of verifying livestock depredation by snow leopard would also be appropriate. The compensatory system may involve, e.g., ecotourism or cottage industry.

Another possible improvement of snow leopard conservation management, is to decrease the human-snow leopard conflict. One of the possible ways is providing a legal mechanism for herders of how to remove individual snow leopards liable for repeated livestock depredations. Better protection of snow leopard would avoid larger predation of livestock and enhancement of human-predator conflict.

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